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Full Length Research Paper

Water management and reuse opportunities in a thermal power plant in Jordan

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The Rehab power plant located in the Northern part of Jordan is presented as a case study of industrial water management. This power plant consumes boiler feed water in the amount of 200 m^3/d of the fresh ground water available from nearby wells and it produces 193 m^3/d of wastewater. Fifty seven water samples were taken from the different water treatment unit's effluents to evaluate the efficiency of these treatment units. Also, sixteen samples from the generated waste streams were taken and analyzed to characterize the wastewater of the different streams. It was found that the water treatment system provided water of much higher quality than needed for the boiler feed. The practice at the power plant was to dispose of the generated wastewater into an evaporation pond that caused non compliance with environmental regulations and discarding of significant water reuse opportunities. It was found that 131 m^3/d of the wastewater were of high quality and could be recycled inside the power plant after treatment by the existing water treatment system. Other reuse options were discussed and recommendations were provided for better operation of the water treatment systems and for reuse of the industrial water. The given scenarios will result in monetary savings and in aesthetical benefits.

Key words: Boiler blow down, industrial water reuse, industrial water treatment, power plants, waste management.

INTRODUCTION

Jordan is a developing country with very limited resources. The increasing demand for water and energy are the main challenges that face the development of the country. These challenges are due to the fact that Jordan is still relying on the conventional sources of both water (that is, groundwater and surface water) and energy (that is, fossil fuel). The main challenge that faces the use of fossil fuel is that it has to be imported from other countries, which means economical challenges. On the other hand, the use of fossil fuel is known to result in environmental pollution. The challenges that are facing the water sector are of twofold: (1) The quantity of fresh water is very limited and it does not satisfy the increasing demand and, (2) The quality of the available quantity of fresh water is continually deteriorating because of pollution resulting from the development activities.

Electrical power plants are essential for the development of the country. They consume significant amount of water, so many studies aimed to reduce water consumption in thermal power plants were conducted (Langer et al., 2000; Chien et al., 2008; Veil, 2007). Waste water generated from thermal power plants contains significant concentration of contaminants such as phosphate, ammonia, dissolved solid, metals and hydrazine. For this reason, treatment and reuse of this water were the focus of much ongoing researches. Torabian et al. (2004) studied the removal of heavy metals generated in washing boiler wastewater. Basic pH and flocculation and coagulation method using ferric chloride, ferric sulfate and alum were applied. Saeedi and Amini (2009) used cement and sand to stabilize heavy metals in wastewater

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Table 1. Electrical power plants in Jordan.

Power plant location	Method of energy generation	Water resource	Water consumption (M^3/y)*	Power plant capacity (MW/H)	Energy production (MW/Y)	Water to generated energy ratio (M^3/MW)
Aqaba	Thermal	Sea water and GW	356000	650	5694000	0.062
Rehab	Combined cycle	GW	36500	360	3153600*	0.011
Al-Samrah	Combined cycle	GW	40000	400	3504000	0.011
Zarqa	Thermal	GW	146000	360	3153600	0.046
Manakher	Thermal	GW	40000	400	3504000	0.011
Total			627500	2170	19009200	

*Boiler feed water

sludge from power plants air heater washing. Jae-Bong et al. (2006) used a membrane capacitive deionization to test desalination performance for power plant wastewater. It was concluded that the used system could successfully be applied for the reuse of power plant wastewater. Schiavi et al. (1989) studied the effects of waste water from electric power plant on the earliness and yield of asparagus.

Though dealing with the challenges facing both water and energy are important, the water challenges in Jordan were considered more vital and thus were superior to deal with; because of the life threatening situation resulting from the severe shortage of water needed for the different uses specially for drinking. Thus, when different uses of water compete, priority is obviously given to secure the drinking water demands. This paper discusses a case study of the water used by a power plant and the wastewater that it produces.

There are five electrical power plants in Jordan with a total capacity of 2170 mega watt per year (MW/Y) as illustrated in Table 1. The water sources used for the power plants are essentially groundwater or groundwater and seawater as in the case of Aqaba power plant.

This paper presents one of the electrical power plants as a case study, which is located in Rehab (Table 1) within the Governorate of Mafraq in the Northern region of Jordan. The plant produces 360 MW/h, of which 260 MW/h was by simple cycle and 100 MW/h by combined cycle. The plant made in Korea and was put in operation in 2004. Now there are 220 employees working in the plant.

The power plant consumes water in the amount of 200 m^3/d (73000 m^3/year) to compensate the wastewater generated from the water treatment plant and that wasted from the boiler. The power plant uses water of drinkable quality that is obtained from groundwater wells located nearby the plant.

Boiler feed water has to meet special quality requirements to avoid operational problems. Therefore, the available groundwater has to be treated to meet the specifications set by the power plant management personnel. Treatment of water takes place within the treatment plant located on the premises of the power plant. The water treatment plant consists of three stages:

1. Pre-treatment filtration units consisting of:
a. Two pressurized sand filters that are backwashed automatically (each contains anthracite, sand and garnet).
b. Two activated carbon filters.
c. Two micro filters.
2. Two reverse osmosis lines each containing a high-pressure pump and 6 vessels.
3. Demineralization units consisting of:
a. Two cation exchanger.
b. Degassing unit.
c. Two anion exchanger.
d. Two mixed bed exchanger.

The used 200 m^3/d of water were wasted in two portions: the first was that 93 m^3/d (33945 m^3/y) were wasted from the water treatment processes and the other 107 m^3/d (39055 m^3/y) were wasted from the boiler mainly as a blow down wastewater, which was 100 m^3/d. Even though the boiler system was a closed system, other losses from the boiler were estimated to be 7 m^3/d as lost steam. The objectives of this paper are: (1) to evaluate the performance of the water treatment plant, and (2) to provide reuse opportunities for the wastewater generated from both of the water treatment plant and the power plant processes.

METHODOLOGY

Fifty seven water and sixteen wastewater samples were collected during the period of the study that lasted from September 2008 to Jun 2009. Since the plant is in a continuous operation, there was no change in water consumption rate or in the generated wastewater. All samples were analyzed in Al Huson College/Environmental Engineering laboratory. The procedures of the Water and Wastewater Standards Methods were used for the collection, preservation and analysis of the samples [APHA, 1998]. If delay before analysis was expected, the samples were preserved and stored according to the recommended procedure in the standard methods. Table 2 presents the identification numbers of the methods used for testing of the different water quality parameters.

Table 2. Methods used for the analysis of the different water quality parameters [APHA, 1998].

Parameter	Method N.
PH	4500-H+B
EC	2510B
Alkalinity	2320A
TDS	2540C
Cl	4500-Cl-C
R-Cl_2	1253
SiO_2	859
Turbidity	2130B
T-Fe	MHi 98/117
PO_4	4110B
NH_3	4500-NH_3D

Some parameters were analyzed by stationary instruments (spectrophotometer gamma brand for SiO_2, PO_4, T-Fe and Hydrazine), or by portable instruments (pH, Turbidity, R-Cl_2, EC, TDS) and by titration (Alkalinity, Cl).

The laboratories results were analyzed and recommendations regarding water management were provided. The locations of the water and the wastewater samples are as follows:

1. Water samples were collected from the following locations:
a. The inlet of the water treatment plant representing the raw groundwater.
b. The effluent of the sand filter units.
c. The effluent of the activated carbon units.
d. The effluent of the micro filter units.
e. The effluent of the reverse osmosis units.
f. The effluent of the cation exchanger unit.
g. The effluent of the degassing units.
h. The effluent of the anion units.
i. The effluent of the mixed bed unit.
2. Wastewater samples were collected from the following locations:
a. The reverse osmosis brine water.
b. The boiler blow down wastewater.
c. The conservation wastewater.

RESULTS AND DISCUSSION

Raw water quality

The water samples were analyzed for the water quality parameters and then the results values were compared with those specified by the power plant specifications as shown in Table 3. Purity of water used in thermal power plants was determined by many quality parameters such as pH, electric conductivity (EC), total hardness (TH), alkalinity (ALK), total dissolved solids (TDS), chloride (Cl^-), residual chlorine (R-Cl_2), silica (SiO_2), turbidity (TURB) and total iron (T-Fe).

The groundwater (obtained from the groundwater wells located near the power plant) had a pH value of 7.68 and it was lower than that specified for the boiler feed water which was in the range of 8.5 to 9.5. When the boiler water pH drops below 8.5, a corrosion called acid attack can occur. On the other hand, caustic attack on boilers is a localized attack due to extremely high pH. For this reason boiler water pH should be controlled to prevent caustic gouging (Parthiban, 2009).

While P-alkalinity (using phenolphthalein indicator) of the groundwater was zero (mg/l as $CaCO_3$) and was lower than that specified for the boiler feed water, the M-alkalinity (using Methyl orange indicator) concentration was higher than the specified value. Control of causticity in boiler water is important to avoid corrosion from acid, promote good reaction between impurities, maintain impurities as dissolved solid, and ensure the desired relationship between calcium and phosphate. Alkalinity or causticity above desired limits can cause corrosive attach or carryover (DOA, 1989).

The values of all of the other parameters shown in Table 3 (that is, conductivity, total hardness, SiO_2, TDS, turbidity, total iron and Cl^-) exceeded those specified by the power plant. Therefore, it is necessary to treat the groundwater to meet the requirements of the power plant specifications. The main objectives of water treatment were to: (1) minimize corrosion of boiler and distribution system, (2) minimize boiler scale deposit, (3) improve efficiency of operation, and (4) control carryover phenomenon (DOA, 1989).

Proper treatment of boiler feed water is an important part of operating and maintaining a boiler system. As steam is produced, dissolved solids become concentrated and form deposits inside the boiler. This phenomenon leads to poor heat transfer and reduces the efficiency of the boiler. Dissolved gasses such as oxygen and carbon dioxide react with the metals in the boiler system and lead to boiler corrosion. The bad maintenance of boiler and feed water chemistry are the main causes of the depreciation, leading to various types of corrosion mechanisms.

Jonas (1987) found out that about 50% of the turbines for which deposits were collected had chloride and sulfates in deposits at concentrations above 0.25 wt %, which can potentially be corrosive.

Reduction of silica concentration in the boiler water is the most significant factor in minimizing turbine silica deposits. After silica enters the boiler water, the usual corrective action is to increase boiler blow down (to decrease the boiler water silica to acceptable levels) and then to correct the condition that caused the silica contamination (Lorch, 1981).

Other contaminants, which may enter the boiler and form porous deposition, include iron, copper, mud, sand, silt, clay and dirt. Localized corrosion damage is encouraged at these deposits (DOA, 1989).

Hardness in water is the result of the presence of calcium and magnesium, which may be deposited as scale. Most of the calcium and magnesium entering the boiler or boiler water system is combined with either carbonate or bicarbonate and is referred to as carbonate hardness (DOA, 1989).

Table 3. Groundwater quality as compared to water quality specification set by the power plant personal.

Water quality parameter	Unit	Water quality parameter value for the groundwater source	The required water quality value by the power plant specifications
Conductivity at 25°C	µS/cm	680 (42)	100
pH at 25°C		7.68 (0.23)	8.5 - 9.5
Total hardness	mg/l as $CaCO_3$	260 (16)	0
Ca-H	mg/l as $CaCO_3$	120 (7.6)	0
Mg-H	mg/l as $CaCO_3$	126 (10.6)	0
SiO_2	mg/l	15 (1.3)	1
TDS	mg/l	457 (31.5)	100
Turbidity	NTU	0.5 (.08)	0
P-alkalinity	mg/l as $CaCO_3$	0	> 0.5
M-alkalinity	mg/l as $CaCO_3$	216 (13.8)	5
$R\text{-}Cl_2$	mg/l	< 0.1	Unlimited
T-Fe	mg/l	12 (1.1)	0.03
Cl^-	mg/l	70 (4.4)	0

*number between parentheses is the standard deviation.

Assessment of the water treatment system

pH value

The samples were taken along the water treatment system of the power plant from the effluent of each treatment unit as shown in Table 4. The pH value of the groundwater source was 7.68 and this value did not change through the sand and the carbon filtration because this stage included only physical process without adding any chemicals that could affect pH. The pH decreased from 7.68 to 7 through the micro filtration and consequently to 6.2 in the effluent of the RO unit as a result of the HCl acid injection that preceded both of these treatment units. Another drop of pH from 6 to 3.8 was shown in the cation exchange effluent as a result of the formation of HCl through the cation exchanger

The removal of the CO_2 gas in the degassing unit resulted in a small increase in pH value from 3.8 to 4. Another increase of the pH value from 4 to 6.2 was shown in the effluent of the anion exchanger as a result of HCl consumption in this treatment unit, then the pH slightly increased in the mixed bed exchanger effluent. The effluent of the mixed bed exchanger is the boiler feed water, which is required to satisfy the water quality specification presented in the last column of Table 4. The 6.25 pH value of the mixed bed exchanger is lower than the 8.5 value recommended by the power plant specification. Therefore, a pH adjustment is done by the addition of ammonia at the inlet of the boiler to raise the pH to the value required by the boiler feed water specification. This addition to the existing water treatment system is necessary to avoid corrosion and acid attacks and eventually to extend the life of the boiler. Also, hydrazine is added along with the ammonia at the inlet of the boiler to get rid of the oxygen that causes boiler corrosion.

TDS contents

The dissolved solids and conductivity are two measures for the same parameter. Table 4 shows that these two measures did not change through the pretreatment sand and carbon filtration, which was expected. However, they increased after the micro filtration. This increase could be attributed to the acid addition before this process. The reverse osmosis resulted in a 96% reduction of conductivity and of the TDS. The slight increase of the conductivity and the TDS shown in the cation exchanger effluent could be attributed to the release of the replaced cation from the exchanger, however this increase was taken care of through the anion exchanger as can be seen from the very low values in the anion exchanger effluent.

Turbidity contents

Turbidity is a measure of the suspended solids and is usually removed by filtration. The turbidity of the ground water source was 0.5 NTU and it was reduced significantly through the sand filtration to 0.15 NTU and through the micro filtration unit to 0.02 NTU (Table 4). It is important to note that the activated carbon treatment did not contribute to the removal to the turbidity. Actually, the

Table 4. Water quality parameters values through the water treatment plant at the power plant (values are average of 16 samples).

Water quality parameter	Water treatment plant Influent	Pre-treatment filtration effluents			Acid injection and RO effluent	Demineralization units effluent			
		Sand filter effluent	Activated carbon effluent	Micro filtration effluent		Cation exchanger effluent	Degassing unit effluent	Anion exchanger effluent	Mixed bed exchanger effluent
pH	7.6 (0.21)	7.6 (0.2)	7.6(0.24)	7 (0.23)	6.2 (0.21)	3.8(0.1)	4(0.12)	6.2(0.18)	6.25 (0.19)
Conductivity (µS/cm)	680 (42)	680 (43)	680 (41)	795 (43)	29 (2.3)	70 (5.5)	63 (5.1)	0.25 (0.01)	0.05
TDS (mg/l)	457 (32)	457 (34)	457 (34)	508 (36)	19 (2.1)	45 (3.3)	40 (3.0)	0.16 (0.01)	0.03 (.002)
Turbidity (NTU)	0.5	0.15	0.15	0.02	0.01	0.01	0	0	0
SiO_2 (mg/l)	15 (1.3)	15 (1.6)	15 (1.5)	15 (1.4)	0.5 (0.04)	0.5(0.03)	0.1 (0.007)	0.01	0.005
Total hardness (mg/l as $CaCO_3$)	260 (13.4)	260 (15.1)	260 (12.8)	260 (14.8)	6.0 (0.4)	0	0	0	0
Alkalinity (mg/l as $CaCO_3$)	216 (11.1)	216 (12.4)	216 (10.6)	216 (12.5)	12 (0.7)	0	0	0	0
T-Fe (mg/l)	12 (1.01)	12 (.09)	12 (0.090	12 (0.08)	5 (0.03)	0	0	0	0
Cl	70 (4.2)	70 (4.2)	70 (3.9)	90 (5.5)	2 (0.15)	0	0	0	0

*Numbers in parentheses represent the standard deviation values.

activated carbon filtration unit did not contribute to the removal of any of the parameters presented by Table 4. This means that the presence of this treatment unit is not useful and thus is not needed in the existing water treatment system. However, the management personnel at the power plant explained that the activated carbon unit exists as a precaution measure in case they had to add chlorine for disinfection of the influent water, which in this case needs the activated carbon to remove the chlorine that would harm the reverse osmosis membranes. It is important to recommend that there is no need to use the activated carbon unit in the absence of the chlorine addition to save the time and the amount of water that are currently used in backwashing. This could be done by installing a by pass pipe that passes the activated carbon unit.

Silica contents

Silica is anathema to electrical power plants chemists; at pressures over about 40 bars it volatilizes, passes over with the steam, and sublimes from the vapor phase forming a solid deposit on any relatively cool surface. If the cool surface happens to be the turbine blades the resulting solid deposit can have catastrophic effects on the turbine balance. The solubility of silica in water increases with increasing temperature and pressure, so the higher the pressure, the greater the risk of silica deposition (Rigby, 2008). For this reason, silica is a key control parameter for water quality used in thermal power plants. SiO_2 concentration in the groundwater source is 15 mg/l. This concentration did not change through the pre-treatment filtration system. It was reduced to 0.5 mg/l through the RO units and to 0.1 mg/l through the degassing unit. Further reduction of the SiO_2 took place through the anion exchanger to 0.01 mg/l and finally through the mixed bed exchanger to 0.005 mg/l.

Hardness and alkalinity contents

The 260 mg/l as $CaCO_3$ of the total hardness passed through the pre-treatment infiltration units unchanged and then it was reduced to 6 mg/l through the RO units. The 6 mg/l was completely removed through the cation exchanger unit meeting the value set by the power plant specifications. Similarly, the alkalinity passed through the pre-treatment filtration and then was reduced from 216 mg/l as $CaCO_3$ to 12 mg/l through the RO units and then to 0 mg/l through the cation exchanger. Both hardness and alkalinity concentrations remained 0 mg/l throughout the rest of the water treatment plant units which was required for the boiler feed water.

Iron contents

Iron corrosion product is probably the single largest cause of deposit problem in boiler system (DOA, 1989) and as such, should be eliminated from feed water. The total iron concentration in the groundwater source was 12 mg/l and it all passed through the pretreatment filtration units indicating that all of the iron was in the soluble form. The total iron concentration was reduced to 5 mg/l through the reverse osmosis and then to 0 mg/l in the cation exchanger and remained 0 mg/l throughout the rest of the treatment units.

Chloride contents

Finally, the chloride concentration increased from 70 mg/l in the water treatment plant influent to 90 mg/l through the micro filtration unit because of the HCl addition and then it was reduced to 2 mg/l through the reverse osmosis and to 0 mg/l through the ion exchange unit. Then it remained 0 mg/l through the rest of the treatment units.

All of the water quality parameters satisfied the boiler feed water specifications after the cation exchanger units. This means that the rest of the existing water treatment units (that is, the anion exchange units, and the mixed bed exchanger units) were not necessary. However, these units provided significant reduction to the TDS and the SiO_2 only. The question "does this reduction justify the existence of these treatment units?" remains unanswered until a financial study is performed.

Wastewater analysis

According to the current practice at the power plant, the wastewater produced is 193 m^3 every day, plus the wastewater that is produced from the conservation of the boiler practiced once or twice a year. The details of the wastewater production are as follows:

1. Wastewater from the operation of the water treatment plant in the amount of 93 m^3/d explained as follows:
a. Sand filter backwash and rinse in the amount of 18 m^3/d.
b. Activated carbon backwash rinse in the amount of 11 m^3/d.
c. Brine water rejected from the reverse osmosis units in the amount of 36 m^3/d.
d. Backwash and rinses for the demineralization units in the amount of 20 m^3/d.
e. Withdrawn water samples from the sampling ports through the water treatment system in the amount of 8 m^3/d.
2. Wastewater from the boiler in the amount of 100 m^3/d plus 1.452 m^3/d per shutdown explained as follows:
a. Boiler blow down in the amount of 100 m^3/d.
b. Water used for the boiler conservation in case of the boiler shutdown in the amount of 530 m^3/shutdown (one or two shutdowns may be done every year). This amount is equivalent to 1.452 m^3/d per shutdown and it contains hydrazine. This amount is insignificant compared to the other wastewaters.

Adding to the amount of the 193 m^3, an amount of 7 m^3/d was lost as steam (in spite of the fact that the plant is a closed system). This means that the power plant uses an amount of 200 m^3 of the ground water every day. Even though this amount is small compared to the benefits, it is very significant to be managed efficiently because: (1) the available water per capita in Jordan is equal to 120 l/d for domestic use (WAJ, 2008), which means that the 200 m^3/d equal to the share of 1666 people inhibiting a small town. (2) Jordan is one of the most water poor countries in the world and it is ranked the 4th among all countries, where the available water from existing renewable sources are projected to fall to less than 91 m^3/capita/year by the year of 2025, which is very low in comparison with the international water poverty line of 1000 m^3/yr (Alzboon et al., 2008), (3) the more efficient use of water will result in financial benefits to the power plant itself by reducing the water bill, (4) the management of the limited resource of water will reflect the environmental friendly practices of the power plant personnel and will enhance the image of the power plant in the eye of the public as well as of the environmental regulatory institutions.

The current practice of the power plant personnel is to dispose of all of the 193 m^3 wastewater produced every day in an evaporation pond. This practice is being done in response to the recent regulations that prohibits the old practice of disposing of this wastewater into the valleys nearby the power plant.

In order to assess the reuse options of the produced wastewater, each of the wastewater streams was analyzed separately and then recommendations were provided. Of the wastewaters produced from the water treatment plant, the one of major concern was the 36 m^3/d brine wastewater from the reverse osmosis units as it is expected to have most of the removed pollutants specially the TDS. The sand filter backwash water were expected to have high concentration of suspended solids and hence to have high turbidity. In fact the turbidity of the backwash water was measured and found to be 7 NTU. As for the rinse of the activated carbon, it was expected to have the same quality of the water used for backwashing (that is, the groundwater) because it is not removing any pollutants as explained earlier. The only parameter that was removed by the micro filtration is turbidity (Table 4); therefore, its rejected wastewater is expected to have some turbidity.

The majority of the wastewater is generated from the boiler blow down in the amount of 100 m^3/d and an amount of 530 m^3 per shutdown. Due to this, the wastewater from the boiler was sampled and analyzed. Also, because of the concerns about the reverse osmosis brine it was also sampled and analyzed. Table 5 presents the results of the analyzed wastewaters. Table 5 indicates that the only concerns about the boiler blow down were the high temperature and the high iron concentration. The values of the rest of the parameters are within the

Table 5. Wastewater characteristics of the boiler and of the RO brine.

Parameter	Unit	Boiler wastewater		Reverse osmosis brine
		Blow down	Boiler conservation	
Amount	m^3/d	100	530 m^3 (per shutdown once or twice a year)	36
pH	-	8.85 (0.5)	10 (0.55)	7.9 (0.4)
Conductivity	µS / cm	17 (1.0)	0	2500 (118)
Total hardness	mg/l as $CaCO_3$	4 (0.17)	0	550 (22)
Total alkalinity	mg/l as $CaCO_3$	0	0	406 (23)
Turbidity	NTU	0	0	0.1 (0.005)
PO_4	mg/l	5 (0.31)	0	0
NH_3	mg/l	0.5 (0.02)	20 (1.1)	0
SiO_2	mg/l	0.33 (0.02)	0	60 (2.8)
TDS	mg/l	8.5(0.35)	0	1600 (62)
Cl^-	mg/l	NIL	0	260 (12)
T Fe	mg/l	0.248 (0.01)	0.2 (0.001)	17 (1.1)
NH_4	mg/l	0.009	200 (9.6)	0
Temperature	°C	100 (6.7)	23 (1.7)	27 (1.3)

*Numbers in parentheses represent the standard deviation values.

required limits of the boiler feed water. As for the water used for the conservation of the boiler, the concern would be about the high pH value and the high NH_4 value. Other than these two parameters, the wastewater meets the requirements of the boiler feed water. The used hydrazine is expected to volatilize as it gets exposed to the atmosphere.

Water reuse scenarios

Discharging to the stream and irrigation reuse

The current practice of disposing of all wastewater in the evaporation pond at the site of the power plant results in dilution of the reverse osmosis brine especially when it is mixed with the higher quality of the blow down wastewater and the other wastewaters. Sixteen samples were taken from the inlet of the pond and the analysis results are shown in Table 6. These results were compared with the specifications of the ruse of water for discharge to streams and for irrigation. Except for pH the wastewater satisfies the discharge to the streams and the irrigation specifications, therefore, it is recommended that this wastewater be discharged or reused for irrigation after a pH adjustment.

Reuse of blow down wastewater

Boiler blow down is generally of higher purity than the original source of supply. Thus, untreated boiler blow down can efficiently be recycled for almost any other use in the plant (Mohsen, 2004). The use of the blow down wastewater as a source of water at the inlet of the water treatment plant is an attractive option. The high temperature of the blow down water problem could be solved by either cooling or by storing in a separate closed storage for few days till its temperature becomes suitable for reuse. The savings in the water bill are expected to justify building the storage reservoir. Internal reuse of blow down wastewater will conserve more than 50% of water consumption in the plant. This scenario could be achieved by using these wastewaters alone or by mixing it with the original groundwater currently used for the power plant. Another option would be to cool down the blow down water during winter by using it for heating of the administration buildings. Irrigation reuse with blow down water is shown to be a viable means of saline water reuse, where waters can be used for the irrigation of salt tolerant crops with some reduction in yields (Jury et al., 2007). Backwash water of activated carbon and ion exchanger units (31 m^3/d) could also be reused as a source of raw water.

Reuse of RO brine water

The 36 m^3/d RO brine could be diluted with some of the blow down wastewater and used as a source of water at the inlet of the water treatment plant. Also saline water could be used for irrigation of plants that has high tolerance of high salt concentrations within the power plant vicinity (Jury et al., 2007, Zaka et al., 2009).

Table 6. Evaporation pond wastewater characteristics as compared with the Jordanian specifications for the use of wastewater.

Parameter	Unit	Inlet of the evaporation pond wastewater characteristics	JS1	JS2	JS3
pH at 25°C	---	9.8 (0.42)	6-9	6-9	6-9
Conductivity at 25°C	µS/cm	750 (42)	*	*	*
TH	mg/l as $CaCO_3$	260 (12.4)	*	*	*
T.ALK	mg/l as $CaCO_3$	40 (1.9)	*	*	*
Turbidity	NTU	0.7 (0.04)	**	*	*
PO_4	mg/l	2 (0.01)	15	10	*
NH_3	mg/l	1 (0.04)	*	*	*
SiO_2	mg/l	18 (1.1)	*	*	*
TDS	mg/l	470 (33)	1500	1500	1500
Cl-	mg/l	50 (2.3)	350	400	400
R-CL_2	mg/l	0	*	*	*
T-Fe	mg/l	0.6 (0.04)	5	5	5
NH_4	mg/l	20 (1.1)	*	*	*

JS1 = Water discharged to the stream, JS2 = water reused for cooked vegetable, JS3 = water reused for field crops.
*Unlimited, **limited for TSS (60 mg/l).
Numbers in parentheses represent the standard deviation values.

Conclusion

The power plant of Rehab generates 360 MW/H and it uses 200 m^3/d of the fresh groundwater obtained from wells nearby the plant site. The power plant has a water treatment plant to meet the boiler feed water specifications. The water treatment system consists of three major processes: pre treatment filtration, reverse osmosis and ion exchangers. It was found that the treated water is of much higher quality than needed for the boiler, which results in longer life of the boiler. The power plant generates 193 m^3/d of wastewater out of which 131 m^3/d is of high quality. Three scenarios for water reuse opportunities were discussed: (i) Discharging of the wastewater to the nearby stream and reusing it for irrigation after adjusting the pH, which accommodates the current practice, (ii) Recycling the blow down wastewater to the inlet of the existed water treatment plant, and (iii) Mixing the RO brine water with the blow down wastewater and reusing it for irrigation. On the other hand, recommendations were made regarding the operation of the water treatment plant. It was recommended that there was no need to use the activated carbon unit in the absence of the chlorine addition to conserve the amounts of water that are currently used in backwashing. These recommendations will result in monetary savings and in enhancing the image of the treatment plant in the eyes of the public and the eyes of the environmental regulatory agencies. Further analysis that demonstrates the economic feasibility of reuse alternatives is recommended.

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